3. Daily Breathing Rates

This section describes the analysis of ventilation rate data and activity patterns data to derive a distribution of daily breathing rates for adults and children. In brief, we evaluated data from Adams (1993) on ventilation rates in a cross-section of the population measured while performing specific tasks. Mean breathing rates for specific tasks in the Adams study were then assigned to similar tasks recorded in two large activity patterns surveys (Wiley et al., 1991a and b; Jenkins et al., 1992). Daily breathing rates were then calculated for each individual in the activity patterns surveys by summing minutes at a specific activity times the ventilation rate for that activity across all activities over a 24-hour period. These breathing rates were then used to develop a distribution of breathing rates for children and for adults. A simulated breathing rate distribution for a lifetime (from age 0 to 70 years) was derived from the children and adult distributions.

Discussion of point estimate defaults, as well as breathing rate distributions derived by others and described either in the open literature or in available documents, is included in this chapter. Descriptions of the databases and procedure we used to characterize breathing rate distributions and derive point estimates of breathing rates are presented. The algorithms used to determine inhalation dose and estimated cancer risk are also described below.

In this and subsequent chapters, we follow U.S. EPA's (1992) definitions of exposure and dose. Exposure refers to the condition of a chemical contacting the outer boundary of a human; the chemical concentration at the point of contact is the exposure concentration. Applied dose is the amount of chemical at the exposure barrier (skin, lung, gastrointestinal tract) available for absorption. Potential dose is simply the amount of chemical ingested, inhaled, or in material applied to the skin. For ingestion and inhalation potential dose is analogous to the administered dose in a dose-response experiment. The internal dose is the amount of chemical that has been absorbed and is available for interaction with biologically significant receptors. Doses can be expressed as amount of chemical per day (e.g., mg/day) or amount of chemical per unit body weight per day (e.g., mg/kg-day).

3.1 Introduction

Exposure to airborne chemicals occurs via inhalation, and subsequent absorption across the lung or the mucosa of the upper respiratory tract may result in adverse health effects depending on the chemical's toxicological properties and the concentration in air. The dose of a substance via the inhalation route is proportional to the concentration of the substance at low environmental concentrations and to the amount of air inhaled. The long-term dose is reflective of average daily breathing rates (m^3 or L/kg-day), and average concentration of the substance in air ($\mu g/m^3$). Short-term doses vary with fluctuations in the breathing rate according to the activity level of the individual at the time of exposure as well as with fluctuations in the concentration of the substance in air. Both a point estimate and a stochastic approach to assessing long-term inhalation dose and estimated cancer risk are described below. The point estimates and distribution of breathing rates presented in this chapter are not meant for an acute

1-hour exposure scenario. A distribution of hourly breathing rates would need to be constructed to use in calculating acute doses.

3.1.1 Point Estimate Approach to Inhalation Cancer Risk

In the current calculation of estimated cancer risk from inhalation exposure to carcinogens in air using the point estimate or deterministic approach, the modeled or measured concentration in air is multiplied by the cancer unit risk factor as follows:

$$C_{air} \text{ x Unit Risk Factor} = \text{Risk} \qquad \text{(Eq. 3-1)}$$

Implicit in the unit risk factor is the assumption that a 70 kg human breathes 20 m^3/day. Thus, in the current point estimate approach, a single estimate of breathing rate and body weight is used. Another way to apply a point estimate approach is to calculate dose first and then cancer risk using a cancer potency factor in units of inverse dose. This allows use of alternate breathing rate point estimates. If a different point estimate of breathing rate (other than 20 m^3/day for a 70 kg human) is used, then the dose of the chemical, calculated as in Equation 3-2 below, is multiplied by the cancer potency factor in units of inverse dose $(mg/kg\text{-}d)^{-1}$ to derive a cancer risk estimate. This is the method OEHHA is recommending as it allows alternate point estimates to be used in calculating dose and risk, and allows for separate dose calculations for susceptible subpopulations such as children.

In assessing the noncancer hazard from chronic exposure, a modeled concentration in air of a pollutant is divided by a reference exposure level (REL) in units of $\mu g/m^3$. (Reference exposure levels for chronic exposure are described in the document entitled, Air Toxics "Hot Spots" Risk Assessment Guidelines Part III: Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels (OEHHA, 2000).) The ratio is called the hazard quotient for that chemical. Hazard quotients for each chemical affecting a specific target organ are summed to derive the hazard index for that target organ. Breathing rate is not necessarily explicitly involved in calculating RELs or in the estimate of noncancer hazard index; rather the concentration of the chemical in air is the determining factor.

3.1.2 Stochastic Approach to Inhalation Dose and Cancer Risk

The stochastic approach to estimating cancer risk from long-term inhalation exposure to carcinogens requires calculating a range of potential doses and multiplying by cancer potency factors in units of inverse dose to obtain a range of cancer risks. This range reflects variability in exposure rather than in the dose-response (see Section 1.3). In equation 3-2, the daily breathing rate (L/kg-day) is the variate which is varied for the stochastic analysis.

The general algorithm for estimating dose via inhalation route for this procedure is as follows:

$$\text{Dose} = 0.001 \text{ x } C_{air} \text{ x } [BR/BW] \text{ x } 0.001 \text{ x } A \text{ x } \frac{EF \text{ x } ED}{AT} \qquad \text{(Eq. 3-2)}$$

Where:

Dose =	dose by inhalation, mg/kg-d; represents potential dose; in rare cases where the potency factor has been corrected for absorption, and data are available to allow the dose equation to be corrected for absorption, then the dose is an internal dose.
0.001 =	mg/μg
C_{air} =	concentration in air (μg/m^3)
[BR/BW]=	daily breathing rate (L/kg body weight - day)
0.001 =	correction factor for m^3/L
A =	inhalation absorption factor, if applicable (default = 1)
EF =	exposure frequency (days/year)
ED =	exposure duration (years)
AT =	averaging time; time period over which exposure is averaged, in days (e.g., 25,550 days for 70 years for carcinogenic risk calculations)

Dose is proportional to the concentration in air, the breathing rate, applicable absorption factors, and the amount of time one is exposed (e.g., EF x ED). Section 3.5 focuses on characterizing the distribution of the variate [BR/BW], breathing rate per kg body weight. We describe a distribution of values for this variate useful for stochastic modeling of dose by inhalation. In order to account for any correlation between body weight and breathing rate, the breathing rate is expressed as liters of air per kg body weight per day. A conversion factor is provided in equation 3-2 to convert from liters to cubic meters.

In practice, the inhalation absorption factor, A, is only used if the cancer potency factor itself includes a correction for absorption across the lung. It is inappropriate to adjust a dose for absorption if the cancer potency factor is based on applied rather than absorbed dose.

The cancer potency factor is calculated for lifetime exposure, generally assumed to be 70 years. When evaluating less-than-lifetime exposure, an exposure time adjustment is necessary. The factors EF and ED refer to exposure frequency in days per year and exposure duration in years. For the Air Toxics "Hot Spots" program residential cancer risk estimates, EF is set at 350 days per year following U.S. EPA (1991), and ED is set at three values, 9 years (U.S. EPA, 1991), 30 years (U.S. EPA, 1991) and 70 years. The point estimates for ED are discussed in Chapter 11. The averaging time is set to 25,500 days (70 years) because the cancer potency factors are based on lifetime exposure.

3.2 Methods for Estimating Daily Breathing Rates

Two methods have been reported in the literature to estimate daily breathing rates. These are described briefly below.

3.2.1 Time-weighted Average Ventilation Rates

The time-weighted average ventilation rates method relies on estimates or measurements of ventilation rates at varying physical activity levels, and estimates of time spent each day at those activity levels. An average daily breathing rate is generated by summing the products of ventilation rates (liters/min) and time spent (min/day) at each activity level. While a spirometer provides accurate measures of ventilation rate, most apparati are too cumbersome to wear throughout the day while performing normal activities. Thus, measurements are taken for shorter time periods under specific conditions, e.g., running or walking on a treadmill. Estimates of time spent during a day at varying breathing rates are made difficult because the available measured ventilation rates for specific activities must be assigned to the much broader array of activities that people engage in over the day. Normal daily activities are categorized into sedentary, light, moderate, and heavy. Measured ventilation rates that correspond to activities considered light, moderate, or heavy are then assigned to each normal daily activity in the appropriate category. Activity pattern studies are used to estimate the time spent each day at the assorted daily activities. Point estimates as well as distributions of daily breathing rate can then be calculated.

The advantage of this method is that directly measured data on ventilation rates at various activity levels are used to characterize exposure to airborne substances. California-specific data are now available for both ventilation rates and activity levels with adequate sample size to obtain estimates of daily breathing rate. The disadvantage of this method is that it may be difficult to assign ventilation rates from a defined set of activities to the variety of daily activities. In addition, the data may be inadequate to address the tails of the distribution, e.g., the ventilation rates of individuals engaged in strenuous activity for long periods of time such as athletes or manual laborers. These individuals are at higher risk from exposure to airborne substances.

3.2.2 Estimates Based on Caloric Intake or Energy Expenditure

A second group of methods used to estimate daily breathing rates is based on caloric intake or energy expenditure. These methods assume that ventilation is proportional to energy expenditure and food intake. Estimating ventilation rate through caloric intake relies on estimates of daily food intake and the amount of oxygen (and therefore air) needed to burn the calories consumed, assuming the individual is neither gaining nor losing weight.

The advantage of this method is that in theory it should give accurate ventilation rates if the amount of O_2 consumed per kcal of food ingested and the caloric intake are known. Unfortunately, estimates of daily caloric intake based on food intake surveys such as the U.S.D.A.'s Nationwide Food Consumption Surveys may not be accurate because underreporting of foods consumed is a problem with such surveys (Layton, 1993). In addition, data may not be available to adequately address the tails of the distribution which describe individuals who are very active (e.g., athletes). Very active individuals are at higher risk from exposure to airborne substances because they require more oxygen and so breathe more air than a sedentary individual. It is also unlikely that food consumption surveys adequately capture the caloric intake of such active individuals.

The estimation of ventilation rates from energy expenditures would be accurate if the energy expenditures could be accurately quantified. A disadvantage to estimating ventilation rates via energy expenditure is that one needs to assign energy expenditures to various normal daily activities in order to arrive at a daily breathing rate. This is analogous to the disadvantage of assigning measured ventilation rates from a narrow group of activities to the variety of normal daily activities.

3.2.3 Current Default Values

Many regulatory agencies have used a default daily breathing rate of 20 m^3/day for a 70 kg human. This number is based on the time-weighted average ventilation rate method using assumptions for time spent at varying activity levels and measured breathing rates summarized in Snyder et al. (1975) and U.S. EPA (1985, 1989a). We estimate that 20 m^3/day for a 70 kg person represents approximately the 85th percentile on our distribution of adult daily breathing rates in L/kg-day. In the latest version of the Exposure Factors Handbook, U.S. EPA (1997) recommends a daily breathing rate of 11.3 m^3/day for adult females and 15.2 m^3/day for adult males as a mean value. The average value for men and women combined would be 13.3 m^3/day. U.S. EPA (1997) did not recommend a high-end value for either adult men or adult women.

3.3 Available Data on Breathing Rates

There are a number of sources of information on measured ventilation rates at various activity levels. These sources are useful for looking at exposure scenarios where the activity level is known, and for estimating daily breathing rates under a variety of exposure assumptions.

3.3.1 Compilations of Ventilation Rate Data

The book Reference Man (Snyder et al., 1975), a report by the International Commission on Radiological Protection (ICRP), presents ventilation rates based on about 10 limited studies. The U.S. EPA's Exposure Factors Handbook has a similar compilation of ventilation rates for men, women, and children based on about two dozen limited studies (U.S. EPA, 1989a). The American Industrial Hygiene Council's Exposure Factors Sourcebook (AIHC, 1994) also has a compilation and suggests specific ventilation rates, as well as a distribution of ventilation rates based on the information in U.S. EPA (1989a). Information from these sources is summarized in Tables 3.1, 3.2, and 3.3. The studies compiled in all of these sources have a small sample size and are limited in scope.

Using an assumption of 8 hour (hr) resting activity and 16 hr light activity and the ventilation rates in Table 3.1, ICRP recommends daily breathing rates of 23 m^3/day for adult males, 21 m^3/day for adult females, and 15 m^3/day for a 10 year old child. In addition, assuming 10 hr resting and 14 hr light activity each day, ICRP recommends a daily breathing rate of 3.8 m^3/day for a 1 year old. Finally, assuming 23 hr resting and 1 hr light activity, ICRP recommends a daily breathing rate of 0.8 m^3/day for a newborn.

The U.S. EPA (1989a) compiled ranges of measured values of ventilation rates at various activity levels by age and sex and categorized activity levels as light, moderate or heavy. Mean values are presented below in Table 3.2 as m^3/hr. U.S. EPA (1989a) recommends using 20 m^3/day for adults based on 8 hr resting and 16 hr light activity each day. Also, where appropriate U.S. EPA (1989a) recommends using a distribution of activity levels when known.

For children-specific scenarios, U.S. EPA (1989a) recommends using the ventilation data in Table 3.2 and specific scenario considerations to construct relevant exposure scenarios.

The AIHC Exposure Factors Sourcebook (AIHC, 1994) recommends a point estimate default daily breathing rate of 18 m^3/day for adults. This is based on the ventilation rates compiled in U.S. EPA's 1989 Exposure Factors Handbook and the assumption of 12 hr rest (sleeping, watching TV, reading), 10 hr light activity, 1 hr moderate activity, and 1 hr heavy activity each day. The ventilation rates in Table 3.3 which represent the AIHC's estimates of a minimum, most likely, and maximum breathing rates for adults and 6 year old children, are based on the U.S. EPA's 1989 Exposure Factors Handbook and an assumed triangular distribution. The "most likely" estimates for 6 to 70 year olds and under 6 year olds are 18.9 and 17.3 m^3/day, respectively. The AIHC also recommends a point estimate default value of 12 m^3/day for children 1 to 4 years old by adjusting the ventilation rate for 6 year olds by 0.75 and assuming 12 hr rest (sleeping, watching TV, reading), 10 hr light activity (play), and 2 hr moderate activity (vigorous play) each day.

Table 3.1 Minute volumes from ICRP's Reference Man (Snyder et al., 1975)[a]

	Resting *L/min (m^3/hr)*	**Light Activity** *L/min (m^3/hr)*
Adult M	7.5 (0.45)	20 (1.2)
Adult F	6.0 (0.36)	19 (1.14)
Child, 10 yr	4.8 (0.29)	13 (0.78)
Child, 1 yr	1.5 (0.09)	4.2 (0.25)
Newborn	0.5 (0.03)	1.5 (0.09)

a. Data compiled from available studies measuring minute volume at various activities by age/sex categories

Table 3.2 U.S. EPA Exposure Factors Handbook (1989a) Estimates of Ventilation rate (m^3/hr)

	Resting	**Light**	**Moderate**	**Heavy**
Adult M	0.7	0.8	2.5	4.8
Adult F	0.3	0.5	1.6	2.9
Avg adult	0.5	0.6	2.1	3.9
Child, 6 yr	0.4	0.8	2.0	2.4
Child, 10 yr	0.4	1.0	3.2	4.2

Table 3.3 AIHC (1994) Point Estimate Defaults and Distribution of Breathing Rate[a] Expressed as m^3/day

	Males and Females 6 to 70 years	**Children Under 6 years**
Minimum	6.0	8.3
Most likely	18.9	17.3
Maximum	32.0	28.3

[a.] Data from U.S. EPA (1989a) with an assumed triangular distribution.

3.3.2 Layton (1993)

Layton (1993) published a study estimating breathing rates based on caloric intake and energy expenditures. The premise for calculating these estimates is that breathing rate is proportional to the oxygen requirement for burning the calories consumed. It is also understood that the calories consumed are largely used for daily energy expenditure. Only an insignificant fraction of daily caloric intake is stored as fat. The general equation for this method of estimating breathing rate is:

$$V_E = E \times H \times VQ \qquad \text{(Eq. 3-3)}$$

where:
- V_E = minute ventilation rate in L/min
- E = energy expenditure rate, kJ/min;
- H = volume of oxygen consumed per kJ;
- VQ = ventilatory equivalent (ratio of V_E in L/min to O_2 uptake in L/min)

Layton took three approaches to estimating breathing rates. The first approach used the U.S.D.A.'s National Food Consumption Survey (1977-78) data to estimate caloric intake. The National Food Consumption Survey uses a retrospective questionnaire to record three days of food consumption by individuals in households across the nation, and across all four seasons. Layton recognized that food intake is underreported in these surveys and therefore adjusted the reported caloric intake upwards. The adjustment is based on studies examining the daily energy expenditure of an average person. The second approach to estimating breathing rates involved multiplying the basal metabolic rate (BMR) by energy expenditure factors reflecting that expenditure of energy associated with normal activity which is not accounted for in the BMR. In the third approach, breathing rates were computed for energy expenditures at specific activity levels and summed across a day. The results of Layton's approaches are presented in Table 3.4. Layton did not report distributions of breathing rates.

Table 3.4 Layton (1993) Estimates of Breathing Rates Based on Caloric Intake and Energy Expenditure

Method	Breathing Rate – Men m^3/day	Breathing Rate – Women m^3/day
Time-weighted average lifetime breathing rates based on food intake	14	10
Average daily breathing rates based on the ratio of daily energy intake to BMR	13-17 (over 10 years of age)	9.9-12 (over 10 years of age)
Breathing rates based on average energy expenditure	18	13

3.3.3 Adams (1993)

The California Air Resources Board (CARB) sponsored a study in 1993 of measured ventilation rates in people performing various laboratory and field protocols (Adams, 1993). The primary purposes of the CARB breathing rate study were to 1) identify mean values and ranges of minute ventilation (V_E) for specific activities and populations and 2) to develop equations that would predict V_E based on known activities and population characteristics. The subjects in this study were 160 healthy individuals of both genders ranging in age from 6 to 77 years. An additional forty 6 to 12 year olds and twelve 3 to 5 year olds were recruited for specific protocols. Subjects completed resting and active protocols in the laboratory, and usually one or more field activities. Data on V_E, heart rate (HR), breathing frequency (f_B), and oxygen consumption were collected in the laboratory. Data collected in the field were limited to V_E, HR, and f_B.

The laboratory resting protocols consisted of 25 minute phases each of lying, sitting, and standing, with data collected during the last 5 minutes of each phase. The active laboratory protocols consisted of walking and running on a treadmill. Data were collected the last 3 min of a 6 minute duration at each speed.

All children completed spontaneous play protocols. Older adolescents (16-18 years of age) completed car driving and riding, car maintenance (males), and housework (females) protocols. Housework, yard work, and car riding and driving protocols were completed by all of the 19 to 60 year old adult females and by most of the senior (60-77 years of age) adult females. Adult and senior males completed car riding and driving, yard work, and mowing protocols. In addition, a subset of young/middle-aged adults completed car maintenance and woodworking protocols. Car riding and driving protocols were 20 minutes long; the others were 30 minutes long. Each protocol was done twice. Heart rate, V_E, and f_B were measured continuously during the field protocols using equipment that minimized restriction of normal movement.

Table 3.5, taken from the Adams (1993) report, provides mean V_E (L/min) for lying, sitting, standing data for young children (ages 3 to 5), children (ages 6 to 12), adult females, and adult males. Adams also presents V_E values for various walking and running protocols for adults in their report. These values are similar to those reported for similar activities in other studies. Results of the field protocols are summarized in Table 3.6 which provides mean V_E for the various activities.

These investigators found that HR correlated well with V_E only in the active laboratory protocols. Heart rate correlation with V_E dropped for field protocols. Mean HR at a given V_E for active field protocols were consistently higher than those found for the walking and running protocols in the laboratory. The investigators attributed the higher HR in field protocols to greater HR that occurs at a given V_E in activities requiring significant arm work (e.g., the field protocols) than in those involving leg work (e.g., the treadmill protocols). A wide variation in individual intensity of effort across subjects in the field protocols was also noted. This study also reflected the higher V_E per m^2 body surface area in children and young adolescents than in adults. The implication is that for a given activity and concentration in air, children are experiencing higher doses on a mg per kg body weight basis than adults.

Table 3.5 Adams (1993) Mean V_E (L/min) by Group and Activity for Laboratory Protocols

Activity	Young Child (age 3-5)	Child (age 6-12)	Adult F	Adult M
Lying	6.19	7.51	7.12	8.93
Sitting	6.48	7.28	7.72	9.30
Standing	6.76	8.49	8.36	10.65

Table 3.6 Adams (1993) Mean V_E (L/min) by Group and Activity for Field Protocols

Activity	Young Child (age 3-5)	Child (age 6-12)	Adult Female	Adult Male
Play	11.31	17.89		
Car driving			8.95	10.79
Car Riding			8.19	9.83
Yard Work			19.23	26-32
Housework			17.38	
Car Maintenance				23.21
Mowing				36.55
Woodworking				24.42

3.3.4 Linn et al. (1993)

Individuals whose jobs require hard physical work breathe more on a daily basis than others in sedentary jobs. Linn and colleagues used the heart rate measurements of 19 construction workers to estimate ventilation rates (VR) throughout a day on the job including some time before work and breaks. These investigators calibrated each individual by recording HR and VR at rest and at different levels of exercise. Least squares regression analysis was used to derive an equation predicting VR at a given HR for each subject. The subjects' heart rates were subsequently recorded beginning early in the morning at home and ending in the afternoon when the subjects stopped working. A diary of the subjects' activities was also kept including change in activity type, personal microenvironment characteristics, self-estimated breathing rate (slow, medium, fast) and breathing problems. The subject recorded in the diary from rising (about 5 AM) to getting to work (about 6 AM). From that point, a trained investigator took over the diary recordings, with the subject communicating the information via a hands-free transmitter. Each individual's VR prediction equation was used to calculate VR from the recorded HR data.

For the 19 subjects, a total of 182 hours of HR was recorded, of which 144 hours represents actual work time. The group statistics for VR are provided in Table 3.7. Predicted VR's were distributed log normally, with the arithmetic mean exceeding the geometric mean. The authors of the study note that the 1st and 99th percentiles are out of the calibration range for most of their subjects. Therefore, the means and 50th percentiles are more accurate. The construction workers predicted VR (overall mean = 28 L/min) exceed that of other workers measured in studies by this same group of investigators using the same methodology. The authors also note that the results of this study are in agreement with data of Astrand and Rodahl (1977) for manual workers.

Table 3.7 Ventilation Rates for Construction Workers Adapted from the API (1995) Analysis of Linn et al. (1993)

PID	BW	SA	mean V_E/m^2	V_E/kg BW
1761	81.6	2.01	12.56	0.31
1763	61.2	1.64	15.92	0.43
1764	74.8	1.94	13.82	0.36
1765	65.8	1.87	16.17	0.46
1766	77.1	1.89	10.80	0.26
1767	99.8	2.26	10.43	0.24
1768	70.3	1.85	10.96	0.29
1769	104.3	2.38	17.29	0.39
1770	81.6	1.97	14.01	0.34
1771	68	1.77	16.91	0.44
1772	117.9	2.35	18.36	0.37
1773	77.1	1.93	14.52	0.36
1774	68	1.81	14.56	0.39
1775	68	1.79	20.09	0.52
1776	81.6	2.0	12.97	0.32
1778	99.8	2.31	18.46	0.43
1779	79.4	1.97	22.10	0.55
1780	109.8	2.38	12.40	0.27
1781	74.8	1.82	13.47	0.33
ALL	82.15	2.00	15.12	0.37

PID = personal identification for each subject
BW = body weight in kg
SA = surface area in m^2
V_E = minute ventilation rate in L/min

3.3.5 U.S. EPA Exposure Factors Handbook (1997)

The U.S. EPA Exposure Factors Handbook (1997) recommendations are summarized in Tables 3.8 and 3.9. The U.S. EPA (1997) has made recommendations for daily breathing rates for specific age ranges, with separate rates for females and males above the age of 9 (Table 3.8). Recommendations for hourly rates for children, adults and outdoor workers are provided for resting, sedentary, light, moderate, and heavy activities.

The recommendations for infants and children's average daily breathing rates are based on Layton (1993), using the first approach in his paper (Table 3.4). The average daily breathing rates for adult men and women are based on the averages of all three approaches used by Layton

(1993). The values which are averaged do not vary greatly. The Layton (1993) study is discussed above in Section 3.3.2. There are no recommendations for distributions or high end values.

The short term hourly mean inhalation rate recommendations for children are based on averaging values for resting, sedentary, light, moderate, and heavy activities from the studies of Adams (1993) (lab and field protocols), Layton (1993) (short-term data), Spier et al. (1992) (ages 10-12) and Linn et al. (1992) (ages 10-12). U.S. EPA (1997) discusses Linn et al. (1992) which recorded HR and activity diaries in healthy and asthmatic children and adults, and Spier et al. (1992) in which V_E was estimated from HR in elementary and high school students who kept activity diaries. The Adams (1993) study is discussed in detail above in Section 3.3.3. The mean short term hourly rate recommendations for adults are based on averaging values from Adams (1993) (lab protocols and field protocols), Layton (1993) (short term exposure and third approach) and Linn et al. (1992). The outdoor worker short term inhalation rates for mean and high end are based on Linn et al. (1992 and 1993). The values which are averaged for the recommendations do not vary greatly. There are no recommendations for distributions for any of the short-term, hourly ventilation rates for children, adults or workers.

Table 3.8 U.S. EPA Exposure Factors Handbook (1997) Recommended Values for Breathing Rate for Long-term Exposure

	Mean (m^3/day)
Infants	
<1 year	4.5
Children	
1-2 years	6.8
3-5 years	8.3
6-8 years	10
9-11 years	
Males	14
Females	13
12-14 years	
Males	15
Females	12
15-18 years	
Males	17
Females	12
Adults (19-65+)	
Females	11.3
Males	15.2

Table 3.9 U.S. EPA Exposure Factors Handbook (1997) Recommended Values For Breathing Rate For Short-Term Exposure

	Mean (m^3/hour)	Upper %tile (m^3/hour)
Adults		
Rest	0.4	
Sedentary Activities	0.5	
Light Activities	1.0	
Moderate Activities	1.6	
Heavy Activities	3.2	
Children		
Rest	0.3	
Sedentary Activities	0.4	
Light Activities	1.0	
Moderate Activities	1.2	
Heavy Activities	1.9	
Outdoor Workers		
Hourly Average	1.3	
Slow Activities	1.1	
Moderate Activities	1.5	
Heavy Activities	2.5	3.3

3.4 Ranges of Ventilation Rates

OEHHA/ATES staff used the raw data from the CARB-sponsored study (Adams, 1993) to evaluate ranges of minute ventilation (V_E) at various activities by gender and age. The program SAS® was used to perform univariate analysis to develop these ranges. The SAS® Univariate procedure provides basic descriptive statistics, such as the mean, standard deviation, variance, and sample size. PROC Univariate was also used in SAS® to characterize the distributional attributes of the V_E data such as skewness, kurtosis, and the percentiles of the distribution.

Since the body weights of individuals in Adams (1993) were available from the raw data, we divided the V_E for each individual by their body weight and expressed ventilation rates as L/min - kg body weight. This helps to account for correlation between ventilation rate and body weight. Analysis of variance was used to determine if combining the weight-adjusted ventilation rates across sexes or ages for the various protocols was appropriate. Variance in body weight explained much of the variance in ventilation rates. The purpose of combining groups is to increase the sample size and therefore the stability of the quantile estimates. If the difference between groups was significant at $p<0.1$, then the groups were not combined. However, in a number of instances it was possible to combine groups to increase the sample size.

Tables 3.10 through 3.14 provide the moments about the mean and selected percentiles of the distribution of breathing rate in L per minute per kg body weight for selected lab and field activities for male and female adults. The tables indicate when groups were able to be combined to determine the mean and moments of the distribution. Data sets were selected to represent ventilation rates at resting, light, moderate, moderately heavy, and heavy activities. The mean ventilation rate recorded while subjects were lying down was chosen to represent ventilation during sleep and rest. The mean ventilation rate recorded while subjects were standing was used to represent ventilation rate during light activity. Mean ventilation rate while doing yard work was used to represent ventilation rate at moderate activity levels. The mean ventilation rates measured while subjects were running were used to represent ventilation rate during heavy activity. All running speeds and both sexes were combined to obtain a mean and moments about the mean for heavy activity. Finally, we took the mean of the means of moderate ventilation rate and heavy ventilation rates to represent a ventilation rate during moderately heavy work. Mean ventilation rate recorded in the field protocol while subjects were driving a car was used for time spent in a car and for those whose occupations involve driving (e.g., truck drivers). As described in Section 3.5, these ventilation rates are used in conjunction with data from the CARB-sponsored Activity Patterns surveys (Wiley et al., 1991a and b) on the time spent by each individual at specific activities to characterize the distribution of daily breathing rate by gender and age group using the time-weighted average breathing rate approach.

Additional information on range and distribution of ventilation rates comes from the study by Linn et al. (1993) on ventilation rates of construction workers. Construction workers include individuals working hard manual labor for prolonged periods throughout the day. These individuals would be expected to have higher daily breathing rates than sedentary office workers, for example. Linn and colleagues present their data as means and offer the 1st, 50th and 99th percentile of the distribution of minute ventilation rates measured via the heart rates in each subject (see description above) (Table 3.15). The American Petroleum Institute developed ranges of ventilation rates from Linn's study (API, 1995). However, OEHHA has not used these data in developing distributions for breathing rate for two reasons. First, the breathing rates in the Linn study include time off work as well as time doing work. Staff were unable to satisfactorily adjust the Linn breathing rates for time spent actually working. Thus, we could not assign the ventilation rates from the Linn study to the time spent at work as recorded by construction workers in the activity patterns study (Wiley et al., 1991a). Secondly, the ventilation rates derived from heart rate measurements in the Linn study appear to be too low relative to breathing rates measured via spirometry in average individuals doing yard work in Adams (1993). After normalizing to body weight (Table 3.17), the mean ventilation rate from the 19 subjects in the Linn et al. study, 0.37 L/min-kg body weight, was just a little above that measured in Adams (1993) for average people doing yard work, 0.31 L/min-kg body weight. We believe that the Linn et al. (1993) data underestimate ventilation rate of individuals doing manual labor. One would anticipate that construction work is heavier work than yard work done by the average person (not professional gardeners). However, the Linn et al. (1993) data do serve as a useful check on a daily breathing rate for someone whose job involves heavy work. To that end, we used the information in the Linn study to justify developing a "moderately heavy" ventilation rate that is in between the moderate breathing rate and the heavy breathing rate described in the previous paragraph to represent ventilation rate for people in the construction (and similar) trades.

Table 3.10 ***V_E (L/Min) Per Kg Body Weight For Adults "Lying-Down Protocol" (Useful For Sleeping/Resting Activities)***[1]

	Women 19 to <60 years	**Men 19 to <60 years**	**Combined Men and Women**
Number of Subjects	20	20	40
Mean	0.12	0.107	0.114
SD	0.025	0.017	0.023
Skewness	0.331	-0.09	0.489
Kurtosis	0.133	-0.85	0.459
PERCENTILES			
1%	0.075	0.076	0.075
5%	0.076	0.078	0.077
10%	0.088	0.084	0.084
25%	0.108	0.093	0.100
50%	0.115	0.110	0.113
75%	0.137	0.121	0.126
95%	0.169	0.135	0.157
99%	0.173	0.140	0.173
Sample Maximum	0.173	0.140	0.173

1. OEHHA used ventilation rates during the lying-down protocol for time spent sleeping and napping. Men and women were combined as the means were not significantly different; the combined mean was applied to develop the daily breathing rate distribution.

Table 3.11 V_E (L/Min) Per Kg Body Weight For Adults "Standing Protocol" (Useful For Light Activity) [1]

	Adult Men and Women 19-59 years
Number of Subjects	40
Mean	0.131
SD	0.027
Skewness	0.850
Kurtosis	1.367
PERCENTILES	
1%	0.080
5%	0.086
10%	0.105
25%	0.114
50%	0.125
75%	0.144
95%	0.188
99%	0.206
Sample Maximum	0.206

Table 3.12 V_E (L/Min) Per Kg Body Weight For Adults "Yardwork Protocol" (Useful For Moderate Activity)[1]

	Adults 19 to <60 years
N	40
Mean	0.323
Std Dev	0.061
Skewness	0.555
Kurtosis	0.792
PERCENTILES	
1%	0.209
5%	0.228
10%	0.248
25%	0.281
50%	0.316
75%	0.364
95%	0.427
99%	0.496
Sample Maximum	0.496

[1] OEHHA defined yardwork as an activity with a moderate breathing rate. Protocol was combined for both sexes because there is no statistically significant difference in the yardwork breathing rates.

Table 3.13 V_E (L/Min) Per Kg Body Weight For Adults And Adolescents "Running Protocol" (Useful For Heavy Activity) [1]

	Adults & Adolescents 13-59 years
N	76
Mean	0.813
Std Dev	0.149
Skewness	-1.023
Kurtosis	3.059
PERCENTILES	
1%	0.182
5%	0.591
10%	0.653
25%	0.716
50%	0.818
75%	0.926
95%	1.031
99%	1.097
Sample Maximum	1.097

Table 3.14 V_E (L/Min) Per Kg Body Weight For All Ages And Both Sexes "Driving Protocol" [1]

	Adults and Adolescents, Both Genders 13 - 59 years
N	76
Mean	0.143
Std Dev	0.035
Skewness	1.529
Kurtosis	5.031
PERCENTILES	
1%	0.066
5%	0.098
10%	0.109
25%	0.120
50%	0.141
75%	0.162
95%	0.194
99%	0.289
Sample Maximum	0.289

Table 3.15 Group Ventilation Rates (L/Min) Based On Heart Rate Records For Construction Workers (Including Before-Work Time And Breaks), From Linn Et Al. (1993).

Group	Mean ± SD	1st Percentile	50th Percentile	99th Percentile
all subjects	28 ± 12	11	27	65
general/laborers	24 ± 11	8	22	61
Ironworkers	27 ± 11	10	26	54
Carpenters	31 ± 13	13	29	69
office site	23 ± 11	10	20	62
hospital site	31 ± 13	12	30	66

3.5 Use of Activity Patterns and Ventilation Rate Data to Develop Breathing Rate Distribution

3.5.1 CARB-Sponsored Activity Patterns Studies

CARB sponsored two activity patterns studies (Wiley et al., 1991a and b; Jenkins et al., 1992; Phillips et al., 1991) in which activities of 2900 adults and children were recorded retrospectively for the previous 24 hours via telephone interview. In the first study, activities of 1762 California residents 12 years and older were recorded. Time diaries were open-ended with activities named by the respondent recorded in a chronological fashion, along with the time each activity ended, and where the activity occurred. A fairly detailed categorization of job type was also included for each respondent. The activities were later coded for data analysis. Random digit dialing was used after grouping telephone exchanges into South coast region, San Francisco Bay Area, and the rest of the state. Samples were spread throughout the state by deliberate over sampling outside the Los Angeles area. Interviews were conducted over a one year period, roughly balanced across the seasons. In the children's activity patterns study, researchers ascertained the time spent at various activities for 1200 children under age 12. Samples were spread throughout the seasons. The methodology was similar to the adults activity patterns study except that an adult in the household served as a respondent to the telephone questionnaire for the children. Data from these 2 activity patterns studies and the CARB-sponsored study of ventilation rates (Adams, 1993) described in section 3.3.3 were combined to determine time-weighted average daily breathing rates.

3.5.2 Development of Daily Breathing Rate Distributions

We grouped activities recorded in the CARB-sponsored activity patterns studies (Wiley et al., 1991a and 1991b) into resting, light, moderate, moderately heavy, and heavy activities to reflect the breathing rates that could reasonably be associated with that activity for adults (Table 3.16); for children there were only resting, light, moderate, and heavy activities (Table 3.17). Job classification as reported in Wiley et al. (1991a) was used to determine activity levels while at work (Table 3.18). In one case, data were available in Adams (1993) that described ventilation rates for specific activities that correspond well to job categories (e.g., the car driving protocol in Adams (1993) is applicable to cab drivers/delivery workers/truckers). Otherwise we assigned the levels of activity that were most appropriate for that job classification. Most jobs are relatively sedentary in nature and so most people were placed in light activity while at work. Most non-work activities were also placed in the light category. When there were mixtures of job types in a CARB job classification, we used the highest reasonable activity level in that job category. In one case where jobs that belonged in a light activity category (e.g., writers) were also lumped in with those belonging in a heavy activity category (e.g., athletes), we assigned half light and half heavy ventilation rates to that group. Since these job categories constitute only a small fraction of the individuals in the study, the impact of this assignment on the distribution is minimal. For each individual, the time spent at each activity level (resting, light, moderate, moderately heavy or heavy) was summed over the day. A distribution of breathing rates was constructed from the sum of the products of mean ventilation rate assigned to each activity and the time spent at that activity for each individual in the study over a 24 hour (1440 minute) period.

Separate distributions were developed for adults (Table 3.19) and children (Table 3.20). The method used does not account for the variance in ventilation rate; however, that variance is small in Adams (1993) (about 0.2 times the mean) compared to the variance in daily activity from individual to individual in Wiley et al. (1991a and b) (about 5 times the mean). Thus, the interindividual variance in breathing rate is easily overwhelmed by the interindividual variance in activity. Dose via inhalation can be assessed separately for children and adults using the modeled concentration of a contaminant in air and the distribution of daily breathing rates per kg body weight.

For informational purposes, we have also included in Table 3.19 the predicted breathing rates for a 63 kg adult. Similarly, Table 3.20 presents the volume equivalent inhaled per day for an 18 kg child. As discussed in Chapter 10, Body Weight, OEHHA is recommending 18 kg and 63 as time-weighted mean point estimate default body weight values for evaluating risk from age 0-9 and 0-70, respectively. In the interest of simplicity, we are also recommending the use of 63 kg as a mean point estimate of body weight for evaluating risk from age 0-30. Equation 3-2 uses the information on breathing rate in units of L/kg-d.

Table 3.16 OEHHA's Categorization Of Non-Occupational Activities For Adults From A CARB-Sponsored Activity Pattern Study (Wiley Et Al., 1991a).

RESTING ACTIVITIES
Ventilation Rate = 0.114 L/min-kg

Activity No.	Activity Label
ACT45	Sleep
ACT46	Naps

LIGHT ACTIVITIES
Ventilation Rate = 0.131 L/min-kg

Activity No.	Activity Label
ACT06	Mins eating at work
ACT07	Mins for before-after work
ACT08	Mins for break
ACT10	Mins for food preparation
ACT11	Mins for meal cleanup
ACT14	Mins for clothes care
ACT18	Mins for pet care
ACT22	Mins helping teachers
ACT23	Mins for talking and reading
ACT26	Mins for medical care
ACT27	Mins for other child care
ACT32	Mins for personal services
ACT33	Mins for medical services
ACT34	Mins for govt-financial services
ACT35	Mins for car repair services
ACT36	Mins for other repairs
ACT37	Mins for other services
ACT38	Mins for errands
ACT40	Mins for washing and hygiene
ACT41	Mins for medical care
ACT42	Mins for help and care
ACT43	Mins meals at home
ACT44	Mins for meals out
ACT47	Mins for dressing
ACT48	Mins not assigned to activities
ACT50	Mins for student classes
ACT51	Mins for other classes
ACT54	Mins for homework
ACT55	Mins for library
ACT56	Mins for other education
ACT60	Mins for professional union
ACT61	Mins for special interests

LIGHT ACTIVITIES (CONT.)
Ventilation Rate = 0.131 L/min-kg

Activity No.	Activity Label
ACT62	Mins for political and civil
ACT63	Mins for volunteer-helping
ACT64	Mins for religious groups
ACT65	Mins for religious practice
ACT66	Mins for fraternal
ACT67	Mins for child youth family
ACT68	Mins for other organizational
ACT70	Mins for sports events
ACT71	Mins for entertainment events
ACT72	Mins for movies
ACT73	Mins for theater
ACT74	Mins for museums
ACT75	Mins for visiting
ACT76	Mins for parties
ACT77	Mins for bars-lounges
ACT78	Mins for other social
ACT83	Mins for hobbies
ACT84	Mins for domestic crafts
ACT85	Mins for art literature
ACT87	Mins for games
ACT88	Mins for computer use
ACT90	Mins for radio
ACT91	Mins for television
ACT92	Mins for records tapes
ACT93	Mins for reading books
ACT94	Mins for reading magazines
ACT95	Mins for reading newspapers
ACT96	Mins for conversation
ACT97	Mins for writing
ACT98	Mins for thinking relaxing smoking
ACT914	Mins for TV and eating
ACT939	Mins for tv-read

MODERATE ACTIVITIES
Ventilation Rate = 0.323 L/min-kg

Activity No.	Activity Label
ACT12	Mins for house cleaning
ACT13	Mins for outdoor cleaning
ACT16	Mins for other repairs
ACT19	Mins for other house stuff
ACT20	Mins for baby care
ACT21	Mins for child care
ACT24	Mins indoor play
ACT25	Mins outdoor play
ACT30	Mins grocery shopping
ACT31	Mins for durable shopping
ACT81	Mins for outdoor
ACT86	Mins for music drama dance
ACT 801	Mins for golf
ACT 802	Mins for yoga
ACT 803	Mins for bowling
ACT124	Mins for cleaning & laundry together

HEAVY ACTIVITIES
Ventilation Rate = 0.813 L/min-kg

Activity No.	Activity Label
ACT80	Mins for active sports
ACT82	Mins for walking hiking bicycling

CAR DRIVING
Ventilation Rate = 0.143 L/min-kg

Activity No.	Activity Label
ACT03	Mins for travel during work
ACT09	Mins for travel to work
ACT28	Mins for pick-up/drop-off
ACT29	Mins for travel to/from child care
ACT39	Mins for travel goods & services
ACT49	Mins for travel personal care
ACT59	Mins for travel education
ACT69	Mins for travel organizational
ACT79	Mins for travel social events
ACT89	Mins for travel recreation
ACT99	Mins for travel communications

YARDWORK
Ventilation Rate = 0.323 L/min-kg

Activity No.	Activity Label
ACT17	Mins for plant care

Table 3.17 OEHHA's Categorization Of Activities From CARB-Sponsored Children's Activity Patterns Study (Wiley Et Al., 1991b)

RESTING ACTIVITY
Ventilation Rate = 0.2 L/min-kg

Activity No.	Activity Label
act45	mins for sleep at night
act46	mins for naps

LIGHT ACTIVITY
Ventilation Rate = 0.3 L/min-kg

Activity No.	Activity Label
act01	mins unaccounted for
act02	mins for unemployment
act03	mins travel during work
act05	mins for paid work
act06	mins for eating at school/work
act08	mins for watching adult at work
act09	mins for travel to school/work meals
act10	mins for food preparation
act11	mins for meal cleanup
act14	mins for clothes care
act15	mins for car repair
act19	mins for pet care
act22	mins for helping/teaching
act23	mins for talking/reading
act26	mins for medical care
act27	mins for other child care
act28	mins watching someone provide child care
act29	mins for travel to child care
act32	mins for personal services
act33	mins for medical services
act34	mins for govt./financial services
act35	mins for car repair
act36	mins for other repair services
act37	mins for other services
act38	mins for errands
act39	mins for travel for goods/services
act40	mins for washing, hygiene
act41	mins for medical care
act42	mins for help and care
act43	mins for meals at home
act44	mins for meals out

LIGHT ACTIVITY (CONT.)
Ventilation Rate = 0.3 L/min-kg

Activity No.	**Activity Label**
act47	mins for dressing
act48	mins for watching personal care
act49	mins travel to pers care/unclear dest.
Act50	mins for student classes
act51	mins for other classes
act52	mins for unspecified daycare
act53	mins for unused
act54	mins for homework
act55	mins for library
act56	mins for other educ/breaks btwn classes
act57	mins hanging out before/after school
act58	mins watching education
act59	mins for travel to education
act60	mins for meetings of organizations
act68	mins for watching organizational activ
act69	mins for travel to organizational activ
act70	mins for sports activity
act71	mins for miscellaneous events
act72	mins for movies
act73	mins for theater
act74	mins for museums
act75	mins for visiting
act77	mins for bars/lounges
act79	mins for travel to social events
act83	mins for hobbies
act84	mins for domestic crafts
act85	mins for art
act87	mins for indoor games
act88	mins for watching recreation
act89	mins for travel recreation
act90	mins for radio
act91	mins for tv
act92	mins for records/tapes
act93	mins for reading books
act94	mins for reading magazines
act95	mins for reading newspapers
act96	mins for conversations
act97	mins for letters, writing
act99	mins for travel to passive leisure
act149	mins for washing clothes laundromat
act199	mins for travel to home/household act
act301	mins for pickup/drop off dry cleaners
act474	mins for washing and dressing
act549	mins for homework/watching TV
act711	mins for eating and amusements
act875	mins for playing/eating
act877	mins for playing/talking w/family

LIGHT ACTIVITY (CONT.)
Ventilation Rate = 0.3 L/min-kg

Activity No.	**Activity Label**
act879	mins for playing/watching TV
act914	mins for TV/eating
act915	mins for TV/doing something else
act934	mins for reading book/eating
act937	mins for reading/TV
act938	mins for reading/listening to music
act944	mins for reading magazines/eating
act954	mins for reading newspapers/eating
act971	mins for household paperwork
smoke	mins child was around a smoker

MODERATE ACTIVITIES
Ventilation Rate = 0.6 L/min-kg

Activity No.	**Activity Label**
act12	mins for cleaning house
act13	mins for outdoor cleaning
act16	mins for home repair
act17	mins for plant care
act18	mins for other household
act20	mins for baby care
act21	mins for child care
act24	mins for indoor play (childcare)
act25	mins for outdoor play (childcare)
act30	mins for grocery shopping
act31	mins for durable shopping
act76	mins for parties
act78	mins for other social events
act81	mins for outdoor leisure
act86	mins for music/drama/dance
act98	mins for other leisure/being a baby
act166	mins for boat repair
act167	mins for painting room/house
act169	mins for building a fire
act801	mins for golf
act802	mins for bowling, pool, pingpong, pinball
act803	mins for yoga
act811	mins for unspecified outdoor play

HEAVY ACTIVITIES
Ventilation Rate = 0.9 L/min-kg

Activity No.	**Activity Label**
act80	mins for active sports
act82	mins for walking/hiking/bicycling

Table 3.18 OEHHA's Assignment Of Activity Levels To Job Categories From CARB-Sponsored Activity Patterns Study (Wiley Et Al., 1991a)

LIGHT ACTIVITIES
Ventilation Rate = 0.131 L/min-kg

Job Code	Description
1	Managers, administrators and public officials (003-019)
2	Accountants, auditors, underwriters and other financial officers (023-025)
3	Management analysts
4	Personnel, training and labor relations specialists (027)
5	Purchasing agents and buyers (028-033)
6	Business and promotion agents (034)
8	Administrative assistants (037)
9	Armed forces officer or NCO
11	Doctors and dentists (084-085)
13	Optometrists (087)
14	Other health diagnosing occupations: podiatrists, chiropractors, acupuncturists, etc. (088-089)
17	Pharmacists and dietitians (096-097)
18	Therapists: physical therapists, speech therapists, inhalation therapists, etc. (098-105)
19	Health techs (hosp. lab techs, dental hygienists, etc.) (203-208)
20	Elementary/high school teachers (155-159)
21	College /university teachers (113-154)
22	Counselors, educational and vocational (163)
24	Lawyers and judges
25	Social scientists and urban planners: economists, psychologists, sociologists, urban planners (166-173)
28	Engineers, scientists, architects (043-083)
29	Computer programmers (229)
30	Other technicians (draftsmen, other lab techs, airline pilots air traffic controllers, legal assistants, etc. (213-228, 233-235)
31	Retail store owners (243)
32	Retail and other sales supervisors (243)
33	Retail sales workers and cashiers (263-276)
34	Real estate and insurance agents (253-254)
35	Stock brokers and related sales occupations (255)
36	Advertising and related sales occupations (256)
37	Sales representatives – manufacturing and wholesale (259)
39	Other sales occupations (257, 258, 283, 285)
40	Office/clerical supervisors/managers (303-307)
41	Secretaries, typists, stenographers, word processors, receptionists and general office clerks (313-315, 319, 379)
42	Records processing clerks: bookkeepers, payroll clerks, billing clerks, file and records clerks (325-344)
43	Shipping/receiving clerks, stock clerks (364-365)
44	Data-entry keyers (385)
45	Computer operators (308-309)
48	Bank tellers (383)
49	Teacher's aides (387)
50	Other clerical workers (316-318, 323, 345-347, 359-363, 366-378, 384, 389)

LIGHT ACTIVITIES (CONT.)
Ventilation Rate = 0.131 L/min-kg

Job Code	Description
51	Supervisors, protective services (413-415)
52	Supervisors, food services (433)
53	Supervisors , cleaning/building services (448)
54	Supervisors, personal services (456)
56	Health service (dental assistants, nursing aides, attendants) (445-447)
57	Personal service (barbers, hairdressers, public transportation attendants, welfare service aides) (457-469)
74	Supervisors, production occupations (633)
79	Precision inspectors, testers, and related workers (689-693)
87	Railroad (engineers, conductors, other operator) (824-826)

MODERATE ACTIVITIES
Ventilation Rate = 0.323 L/min-kg

Job Code	Description
7	Inspectors and compliance officers (035-036)
12	Veterinarians (086)
15	Nurses (RNs, LVNs, LPNs) (095, 207)
26	Clergy, social, recreation and religious workers (174-177)
38	Street and door-to-door sales workers, news vendors, and auctioneers (277-278)
47	Postal clerks, mail carriers, mail carriers, messengers, etc. (354-357)
55	Cooks, waiters and related restaurant/bar occs. (404, 434-444)
58	Cleaning and building service (maids, janitors, housekeepers, elevator operators, pest control) (416-427)
59	Child care workers (406, 408)
60	Fireman, policemen and other protective services occs. (416-427)
61	Farmers, farm managers/supervisors and other supervisors of agricultural/forestry work (473-477, 485, 494)
64	Graders, sorters and inspectors of agricultural products (488-489)
66	Nursery workers (484)
67	Groundskeepers and gardeners (486)
70	Other farming, forestry, and fishing occupations (483)
71	Supervisors, mechanics and repairers (503)
72	Supervisors, construction trades (553-558)
75	Mechanics and repairers of machinery (505-549)
80	Plant and system operators (water and sewage treatment plant operators, stationary engineers) (694-699)
84	Supervisors, material moving equipment operators (843)
85	Machine operators (703-779)
91	Production inspectors, testers, samplers and weighers (796-799)
92	Supervisors of handlers, equipment cleaners and laborers (863)
95	Service station attendants, car mechanic's helpers, tire changers, etc. (885) Helpers of other mechanics and repairers (864) Vehicle washers and equipment cleaners (887)

MODERATELY HEAVY ACTIVITIES
Ventilation Rate = 0.568 L/min-kg

Job Code	Description
76	Construction trades (carpenters, plumbers, roofers, etc.) (563-599)[1]
78	Precision production occupations (tool and die makers, cabinet makers, jewelers, butchers, bakers, etc.) (634-688)
89	Bulldozer and forklift operators, longshoremen, and other material movers (844-859)
94	Factory and other production helpers (873); Hand packers and packagers (888); EXCEPT construction (889)
96	Garbage collectors, stock handlers, baggers and other movers of material by hand.

HEAVY ACTIVITIES
Ventilation Rate = 0.813 L/min-kg

Job Code	Description
63	Farm workers (479)
90	Fabricators, assemblers and hand working operations: welders, solderers, hand grinders and polishers, etc. (783-795)
93	Construction helpers and laborers (865,869)

CAR DRIVING ACTIVITIES
Ventilation Rate = 0.143 L/min-kg

Job Code	Description
86	Motor vehicle operators (truck, bus taxi drivers) (804-814)

The following mixed category was assigned 1/2 light and 1/2 heavy breathing rate:

27	Writers, artists, entertainers and athletes (183-199)

A preliminary estimation of the best parametric model to fit the distributions described in Tables 3.19, 3.20 and 3.21 was done using the fitting function in Crystal Ball version 4.0. The Anderson Darling criterion was used since this procedure is more sensitive to the tails of the distributions. The following distributions are considered as possible fits for these data: Normal, Triangular, Log normal, Uniform, Exponential, Weibull, Beta, Gamma, Logistic, Pareto and Extreme Value.

The following procedure was used to confirm that the empirical distributions were adequately described by a parametric model and parameters determined by Crystal Ball . To determine if a variate is best characterized by a particular distribution, the data are ranked and the ranks are divided by *n* (sample size) to create values from 0 to 1; these values estimate the cumulative distribution function. The inverse cumulative distribution functions can be applied to these fractional ranks to obtain probability quantile scores which can be compared to the raw data (or the log transformed data) to judge the fit of the distribution. For example, if a data set has a normal distribution, the normal scores should be highly correlated with the original values, and a plot of the scores as a function of the original values should be close to a straight line. Also, if the data are log normally distributed the log transformation of the data should be highly correlated with the normal scores. Therefore, the highest correlation determines the best fit. For example, if the raw scores have a higher correlation than the log transformed, the data are considered normally distributed. The normal scores are computed as follows:

$$y_i = \phi^{-1}(r_i - 3/8)/(n + 1/4)$$

where ϕ^{-1} is the inverse cumulative normal function, r_i is the rank of the *i*th observation, and n is the number of observations for the ranking variable (Blom, 1958; Tukey, 1962). The distributions in Tables 3.19, 3.20 and 3.21 were determined by this method to be adequately fit by gamma distributions.

Table 3.19 Adult Daily Breathing Rates (L/Kg Body Weight - Day)

	All Adolescents (>12 years), and Adults Moments & Percentiles (Empirical Data)	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing rate equivalent for a 63 kg human, M^3/day (Empirical Data)**
N	1579		
Mean	232	233	14.6
Std Dev	64.6	56.0	4.07
Skewness	2.07	1.63	
Kurtosis	6.41	6.89	
%TILES	**L/kg-day**		
1%	174	(Not Calculated)	11.0
5%	179	172.3	11.3
10%	181	178.0	11.4
25%	187	192.4	11.8
50%	209	218.9	13.2
75%	254	257.9	16.0
90%	307	307.8	19.3
95%	381	342.8	24.0
99%	494.0	(Not Calculated)	31.1
Sample Maximum	693		43.7

Table 3.20 Children's (≤ 12 Years) Daily Breathing Rates (L/Kg Body Weight - Day)
*

	Moments and Percentiles from Empirical Data	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing Rate Equivalent for a 18 kg Child, m^3/Day (Empirical Data)**
N	1200		
Mean	452	451	8.1
Std Dev	67.7	66.1	1.22
Skewness	0.957	0.9	
Kurtosis	1.19	4.32	
%TILES	**L/kg-day**		
1%	342.5	(not calculated)	6.17
5%	364.5	360.3	6.56
10%	375	374.9	6.75
25%	401.5	402.7	7.23
50%	441	440.7	7.94
75%	489.5	488.4	8.81
90%	540.5	537.9	9.73
95%	580.5	572.1	10.5
99%	663.3	(not calculated)	11.9
Sample maximum	747.5		13.5

A breathing rate distribution was simulated for age 0-70 from the adult and children's breathing rate distributions, using Latin Hypercube sampling. The simulation was done using an Excel spreadsheet and Crystal Ball , Version 4. The adult and children's breathing rate distributions were entered as custom distributions with the adult breathing rate distribution truncated at age 70. The children's breathing rate distribution is multiplied by 0.17 and added to 0.83 multiplied by the truncated adult breathing rate distribution. The 0.17 and 0.83 represent the respective proportions of time that a person would be a child from age 0 up to 12 and an adult from age 12 to age 70. The effect of different rank order correlations between the children's and the truncated adult distribution were explored. The effect on the 95th percentile of the 0-70 distribution varied only a few percent between a correlation of 0 and 0.8. It was therefore decided to assign a rank correlation of zero. Ten thousand trials were performed. Goodness of fit tests were performed using Crystal Ball version 4. The Anderson Darling statistic is 110.2963 for a Gamma distribution with location, scale and shape parameters of 193.99, 31.27 and 2.46 respectively. In addition, the QQ plot for the Gamma distribution is nearly a straight line indicating a reasonable fit.

Table 3.21 Simulated Lifetime (Age 0-70) Daily Breathing Rates (L/Kg Body Weight – Day)*

	Moments and Percentiles from Simulated Data	**Moments and Percentiles, Fitted Gamma Parametric Model**	**Breathing Rate Equivalent for a 63 kg Adult, m^3/day**
Trials	10,000		
Mean	270.9	271.1	17.1
Std Dev	57.9	48.8	3.65
Skewness	2.18	1.22	
Kurtosis	9.43	5.17	
%TILES	**L/kg-day**		
2.5%	213.7	206.6	13.5
5%	217.1	211.3	13.7
10%	221.6	218.3	14.0
25%	232.9	235.2	14.7
50%	253.1	260.9	16.0
75%	289.0	297.1	18.2
90%	337.8	335.9	21.3
95%	393.4	364.9	24.8
97.5%	434.7	390.9	27.4

Figure 3.1 Simulated Age 0-70 Breathing Rate Distribution with Fitted Gamma Distribution

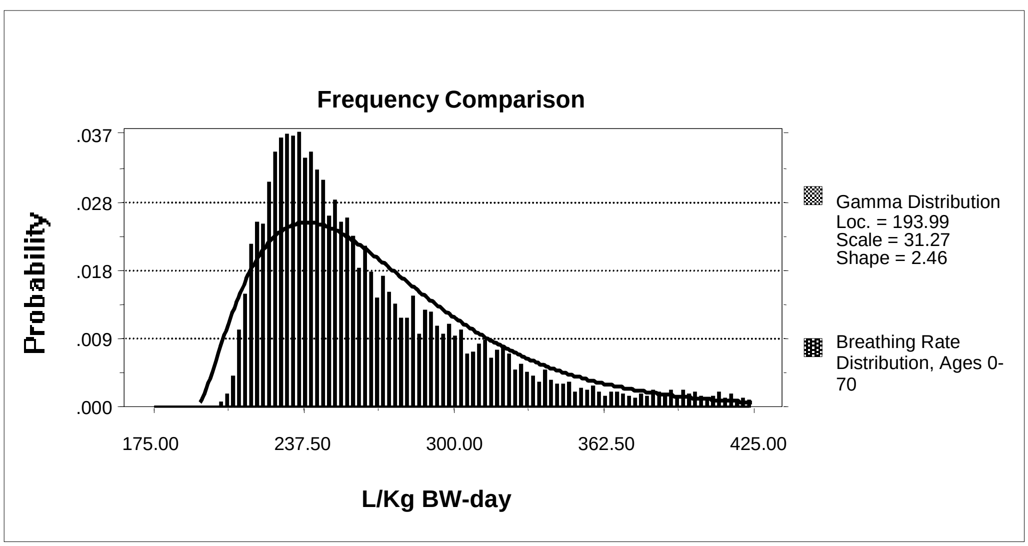
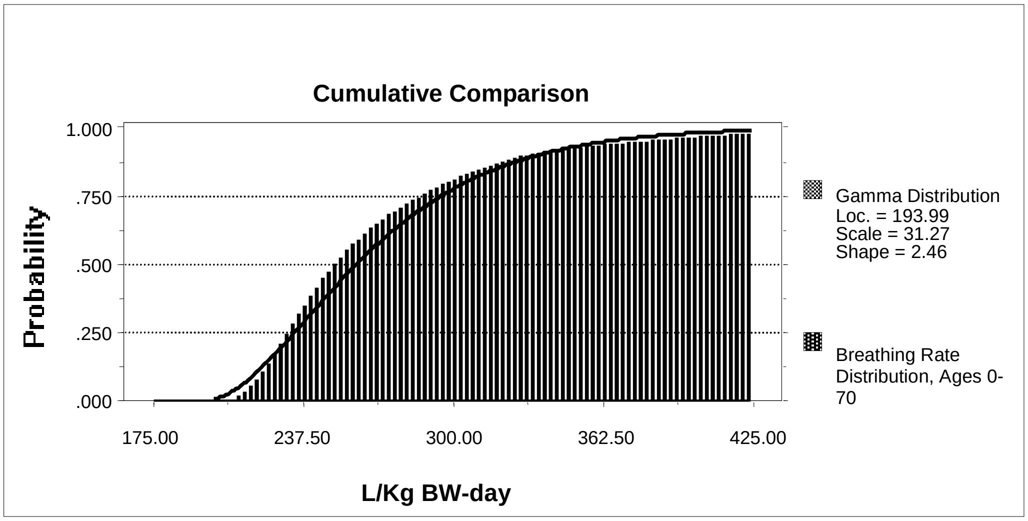


Figure 3.2 Simulated Age 0-70 Breathing Rate Cumulative Probability Distribution with Fitted Gamma Distribution



3.5.3 Evaluating the Validity of the Breathing Rate Distributions

In order to validate the breathing rate distributions, OEHHA examined data on daily energy expenditure. Since we breathe to obtain oxygen to burn calories that we expend, then breathing rate should be proportional to energy expended. In the last decade or so, studies of energy expenditure have been conducted using the doubly labeled water method. The analysis of these data is described in Appendix K. In sum, the use of short-term studies to develop distributions for use in chronic exposure scenarios presents the problem of being unable to characterize an individual over time. Since life changes will impact breathing rates, the distribution developed from short-term data may be an overestimate. However, we believe that the error introduced in this case is minimal. Our breathing rate distribution is narrow - there is only a slightly larger than 2-fold difference between the 5th and 95th percentiles of the adult breathing rate distribution and less than 2-fold difference in the children's. This range is consistent with the range of physical activity indices measured in a number of studies. Relatively longitudinal measurements of total energy expenditure by the doubly-labeled water method in a number of studies are consistent with the caloric equivalents of the OEHHA breathing rate distribution. While the OEHHA breathing rate distribution appears to overestimate energy expenditure in the elderly (over 65 years), it also appears to underestimate energy expenditure in young active men. The documented decrease in energy expenditure appears to occur in the 6th and 7th decades of life. Therefore, by comparison to measures of total energy expenditure, the OEHHA breathing rate distribution is a good approximation of what occurs over a 70 year lifetime.

Figure 3.3 Childrens Breathing Rate Probability Distribution with Fitted Gamma Parametric Model

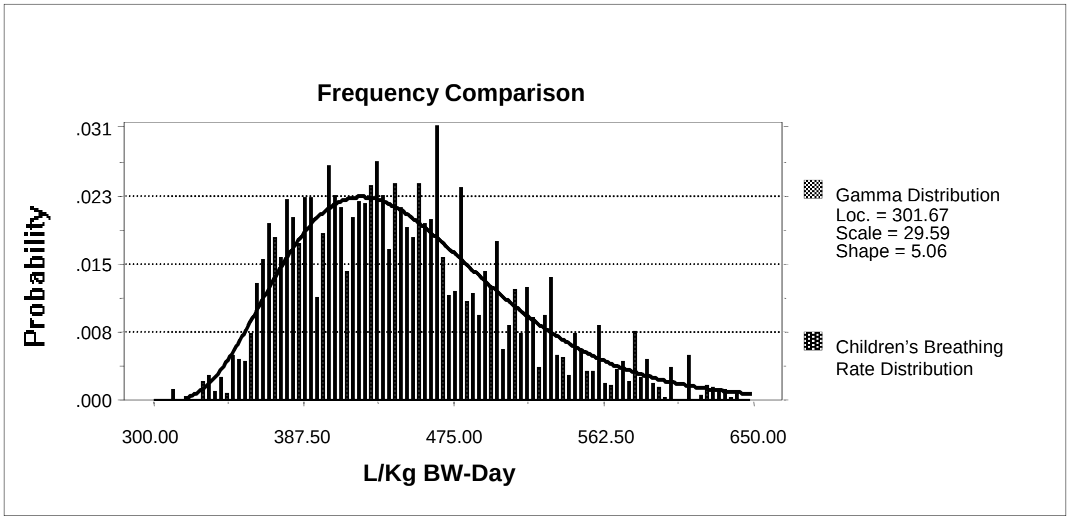


Figure 3.4 Childrens Breathing Rate Cumaulative Probability Distribution with Fitted Gamma Parametric Model

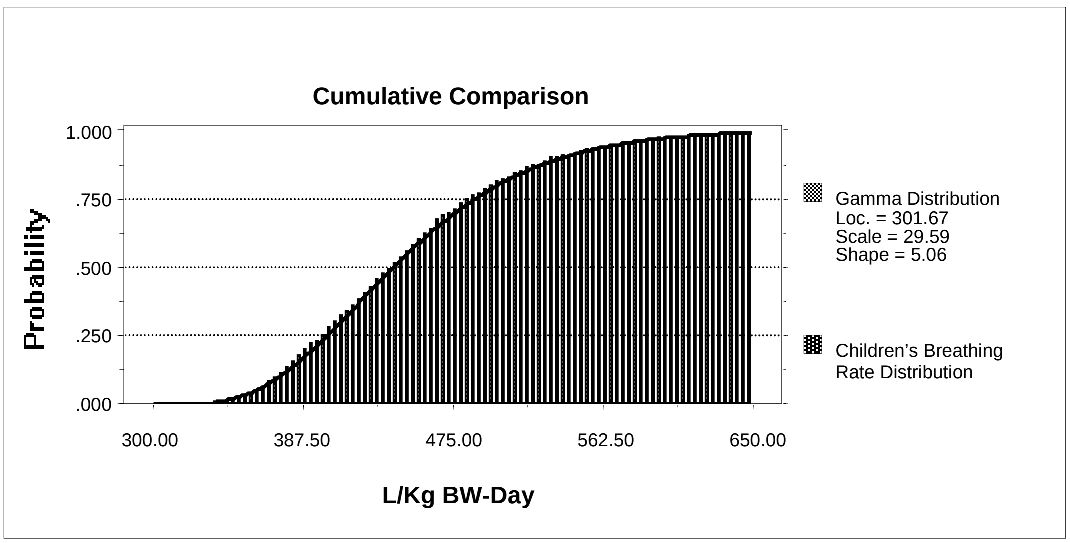


Figure 3.5 Adult Breathing Rate Probability Distribution with Fitted Gamma Parametric Model

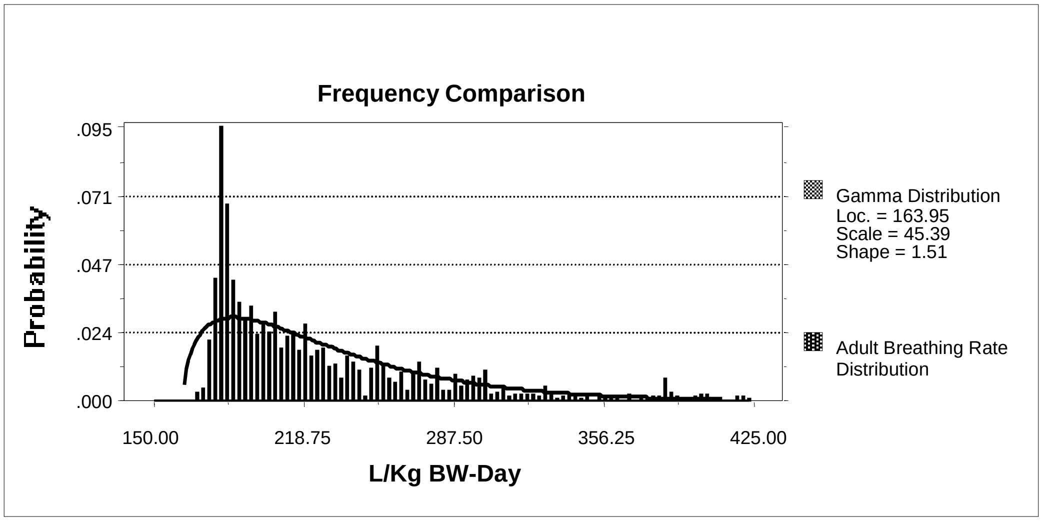
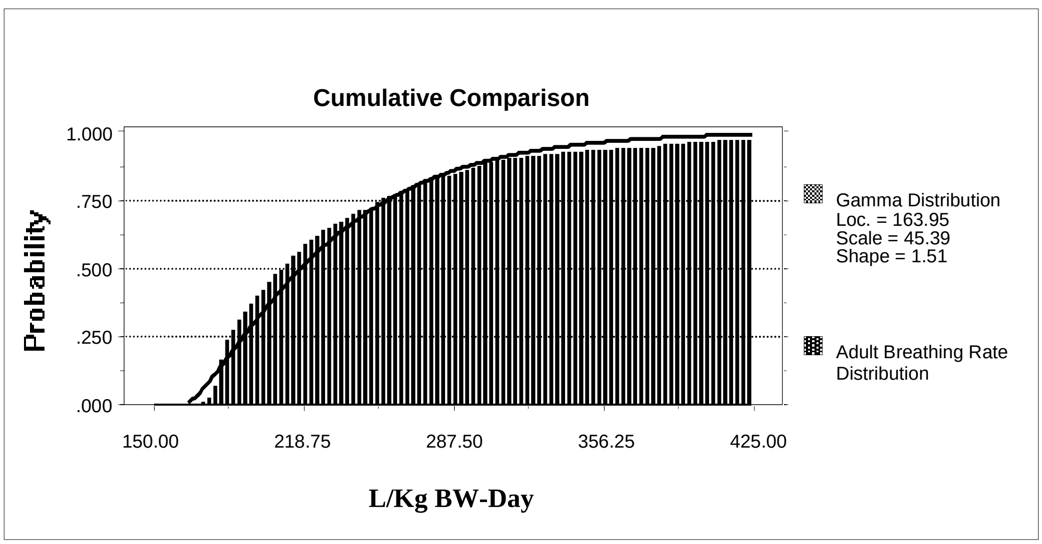


Figure 3.6 Adult Breathing Rate Cumulative Probability Distribution with Fitted Gamma Parametric Model



3.6 Recommendations

Table 3.22 Point Estimates For Daily Breathing Rates [a]

	Adults (>12 yrs)	***Children ($\leq$12 yrs)***
Mean	232 L/kg-day	452 L/kg-day
High End	381 L/kg-day	581 L/kg-day

[a.] Taken from Distributions in Table 3.19 and 3.20.

Table 3.23 Point Estimates For 9, 30 And 70 Years (L/Kg Body Weight - Day)

	9 Year	**30 Year**	**70 Year**
Mean	452	271	271
High End	581	393	393

3.6.1 The Point Estimate Approach

For the point estimate approach, OEHHA recommends that the mean and high-end inhalation dose and cancer risk be calculated for 9, 30 and 70 years using the point estimates presented in Table 3.23. The point estimates of breathing rate for the 9-year scenario are the mean (452 L/kg-d) and 95th percentile (581 L/kg-d) of the breathing rate distribution for children. The point estimates of breathing rate for 30 and 70 year scenarios are the mean (271 L/kg-d) and 95th percentile (393 L/kg-d) of the simulated age 0-70 year distribution. Although it would be possible to generate mean and high end breathing rate point estimates from a simulated age 0-30 year distribution, the values would not be that much different from those of the 0-70 simulated distribution. In the interest of simplicity, it is therefore suggested that the same point estimate values be used for the 30 and 70-year scenarios. These recommendations apply to the Tier 1 and 2 approaches as outlined in Chapter 1.

It may be appropriate under certain circumstances to calculate separate risks for children or adults. The mean and high-end estimates presented in Table 3.21 may be used for these purposes. For this type of approach, children are defined as 12 years or younger.

Since inhalation is nearly always a dominant pathway, the high-end estimates must be used to calculate dose and risk. In addition, it may be appropriate to calculate the inhalation dose and cancer risk using the mean value from the daily breathing rate distribution and to present that along with the dose and risk based on the high-end estimates of daily breathing rate. The dose, derived by multiplying the modeled concentration in air by the breathing rate as in equation 3-2 above, is then multiplied by the cancer potency factor to estimate cancer risk.

A commonly used point estimate for daily breathing rate in risk assessment is 20 m^3/day for a 70 kg human (U.S. EPA, 1989a and 1991). This point estimate is equivalent to 286 L/kg-day and is about the 85th percentile on our distribution of daily breathing rates for adults. Our 70-year time-weighted average body weight is 63 kg. For comparison, the mean breathing rate from our distribution for a 63 kg body weight would be about 17 m^3 per day (see Table 3.21). The 95th percentile breathing rate for a 63 kg person is about 25 m^3 per day.

3.6.2 The Stochastic Approach

We are recommending the distributions of daily breathing rates depicted in Table 3.20 and Figures 3.3, 3.4 for the 9 year exposure scenario and in Table 3.21 and Figures 3.1, 3.2 for 30 and 70 years for use in a Tier 3 or 4 risk assessment. The parametric model recommended for the 9 year scenario is a gamma distribution with location, scale and shape of 301.67, 29.59 and 5.06, respectively. The parametric model recommended for the 0-30 and 0-70 year exposure scenarios is a gamma distribution with location, scale and shape of 193.99, 31.27 and 2.46, respectively. The distributions can be used in a Monte Carlo simulation or similar statistical method to evaluate a range of inhalation doses using Equation 3-2. The distribution is multiplied by the cancer potency factors to describe a distribution of inhalation cancer risks based on variability in exposure.

3.7 References

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